Advanced Materials and Cell Components for NASA's Exploration Missions

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NASA Glenn Research Center

NASA Aerospace Battery Workshop

Holiday Inn Research Park, Huntsville, AL

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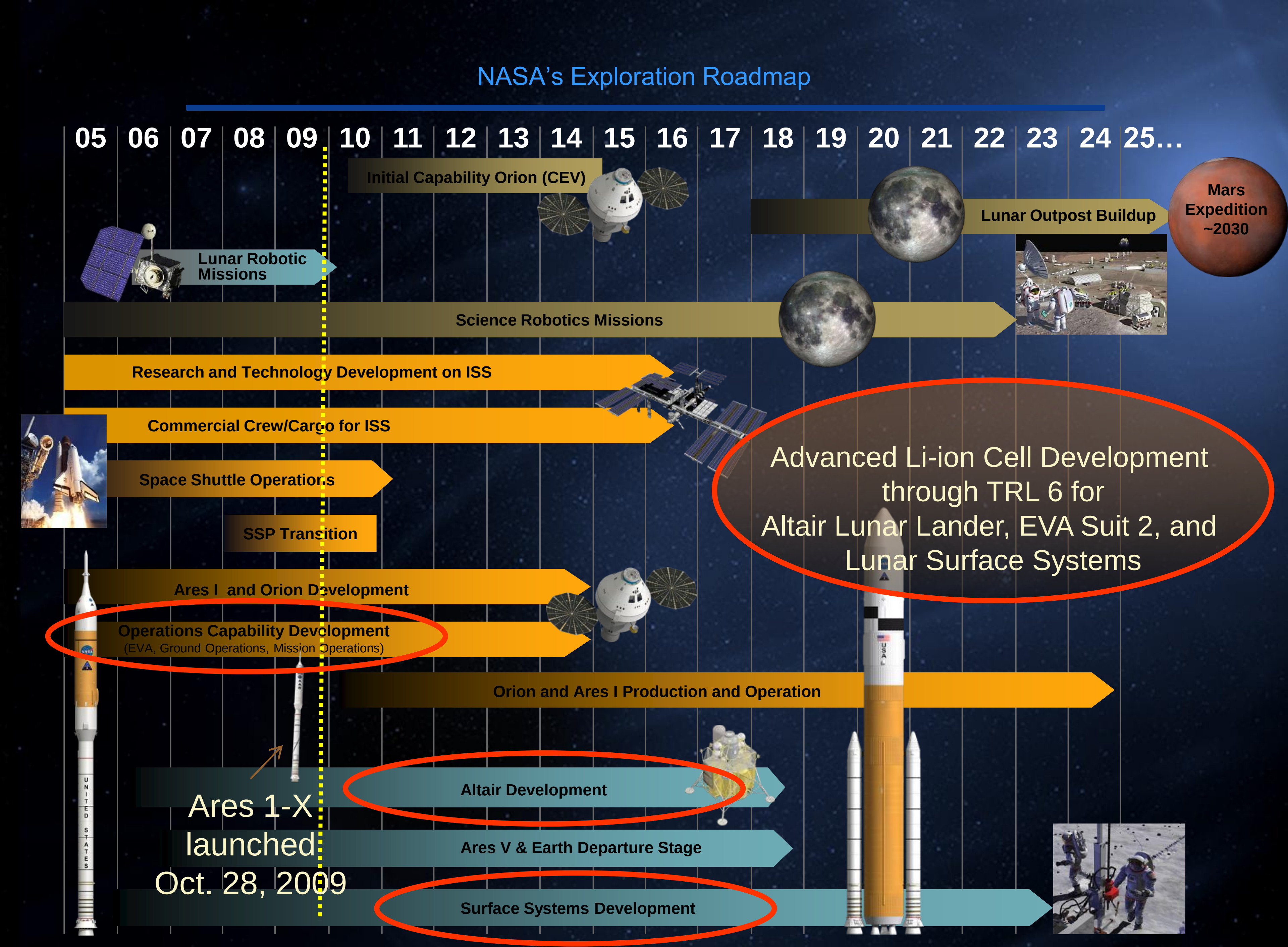

NASA's Exploration Roadmap
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25…
Initial Capability Orion (CEV)
Lunar Outpost Buildup
Mars Expedition ~2030
Lunar Robotic Missions
Science Robotics Missions
Research and Technology Development on ISS
Commercial Crew/Cargo for ISS
Space Shuttle Operations
SSP Transition
Advanced Li-ion Cell Development through TRL 6 for Altair Lunar Lander, EVA Suit 2, and Lunar Surface Systems
Ares I and Orion Development
Operations Capability Development
(EVA, Ground Operations, Mission Operations)
Orion and Ares I Production and Operation
Altair Development
Ares 1-X launched Oct. 28, 2009
Ares V & Earth Departure Stage
Surface Systems Development

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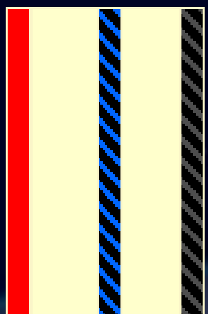
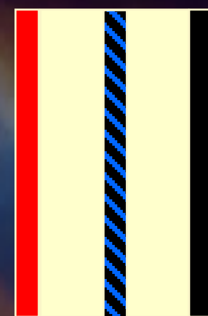
Energy Storage Project Advanced Li-ion Cell Development

High Energy Cell



Conventional Carbonaceous Anode

Ultra High Energy Cell



Si-composite NASA Anode

$Li(LiNMC)O_2$ NASA Cathode

Anode (commercial)
Anode (NASA)
Cathode (NASA)
Electrolyte (NASA)
Separator (commercial)

Safety devices (NASA) Incorporated into NASA anode/cathode

High Energy Cell

•Development targeted for Lunar Surface Systems (Lunar Electric Rover, Portable Utility Pallet)
•Lithiated mixed-metal-oxide cathode / Graphite anode

•$Li(LiNMC)O_2$ / Conventional carbonaceous anode
•**180** Wh/kg (100% DOD) @ cell-level, 0^0C and C/10
80% capacity retention at ~**2000** cycles

•TRL 4: Sept. 2012 TRL 6: Sept. 2013

Ultra High Energy Cell

•Development targeted for EVA spacesuit and Altair Lunar Lander
•Lithiated-mixed-metal-oxide cathode / Silicon composite anode
•$Li(LiNMC)O_2$ / silicon composite
•**260** Wh/kg (100% DOD) @ cell-level, 0^0C and C/10
80% capacity retention at ~**200** cycles

•TRL 4: Aug. 2013 TRL 6: Sept 2014

Preliminary system requirements given in, "Reid, Concha, M., Miller, Thomas B., Manzo, Michelle A., and Mercer, Carolyn M., "Advanced Li-ion Cell Development for NASA's Constellation Missions", NASA Aerospace Battery Workshop, Huntsville, AL, Nov. 2008.

Anodes

- **Goal:** 1000 mAh/g at C/10 (10 hour discharge rate) and 0°C
  - Over 3 times the capacity of SOA Li-ion anodes
  - Threshold value = 600 mAh/g at C/10 and 0°C

Technology Challenges	Current Approaches to Address
Minimize volume expansion during cycling	•Pursuing various approaches to optimize the anode structure to accommodate volume expansion of the silicon •Nanostructured Si composite absorbs strain, resists active particle isolation on cycling •Incorporation of elastic binders in Si –graphite and Si-C matrices •Improvement of mechanical integrity by fabricating structure to allow for elastic deformation
Minimize irreversible capacity loss	•Protection of active sites with functional binder additives •Pre-lithiation approaches are possible •Nanostructured Si resists fracture and surface renewal
250 cycles	Loss of contact with active particles reduces cycle life. Addressing volume changes and improvement of mechanical integrity will improve cycle life

Cathodes

- **Goals:**
  - Specific capacity of 280 mAh/g at C/10 and 0°C to 3.0 V
  - High voltage operation to 4.8 V
  - Improved thermal stability over conventional Li-ion cathodes

Technology Challenges	Current Project Approaches to Address
High specific capacity at practical discharge rates	•Vary stoichiometry to determine optimum chemical formulation •Reduce particle size •Experiment with different synthesis methods to produce materials with physical properties such that their specific capacity is retained on production scale
Low volume per unit mass	•Vary cathode synthesis method to optimize properties that can: •Improve energy density •Improve ability to cast cathode powders •Facilitate incorporation of oxide coatings, which have the potential to increase rate capability and reduce capacity fade to extend cycle life
Minimize 1st cycle irreversible capacity loss and irreversible oxygen loss	•Surface modification via coatings to improve cathode-electrolyte interfacial properties •Improves capacity retention •Reduces capacity fade

Electrolytes

- **Goal:** Develop flame-retardant and/or non-flammable electrolytes that are stable up to 5V

Technology Challenges	Current approaches to address
Electrolyte that is stable up to 5V	Experiment with different electrolyte formulations and additives with potential to improve high voltage stability. Study interactions at both electrodes
Non-flammable or flame retardant electrolyte	Develop electrolytes containing additives with known flame retardant properties. Perform flame retardance assessments on developments that exhibit suitable electrochemical performance
High voltage stable, non-flammable or flame retardant electrolyte (combination of both properties in one electrolyte system)	Combine flame retardant additives with electrolyte formulations with high voltage stability. Operate systems to high voltages and investigate impacts on rate capability, specific energy, energy density and life.
Electrolytes possessing the requisite physical properties to ensure good rate capacity (adequate conductivity) and compatibility (wettability).	Develop electrolytes that are not excessively viscous to ensure that the ionic conductivity is sufficiently high over the desired temperature range and the separator wettability is adequate.

Safety

- **Goal:** Cells that are tolerant to electrical and thermal abuse

Technology challenges	Approaches to address
Safe electrodes	•Develop materials to improve tolerance to an electrical abuse condition •Approach 1: Develop a high-voltage stable (phosphate) coating on cathode particles to increase the safe operating voltage of the cell and reduce the thermal dissipation by the use of a high-voltage stable coating material (cobalt phosphate). •Approach 2: Develop a composite thermal switch to shutdown cell reactions safely using coatings on the current collector substrates
Safe electrolyte	•Development of advanced high voltage, non-flammable/flame-retardant electrolytes (via electrolyte task)

Separators

- **Goals:**
  - Identification of Li-ion cell separator materials that are compatible with the ETDP chemistry and provide an increased level of safety over SOA Li-ion cell separators
  - Current efforts are focused on assessment of developmental (i.e., company IRAD materials) and commercial separator materials
- **No Significant Technology Challenges:**
  - Design optimization for high porosity and low ionic resistance to facilitate ionic conductivity while maintaining mechanical strength
  - Shutdown separators must “shutdown” cell reactions at optimum temperature without shrinking or losing mechanical integrity

NASA Exploration Technology Development Program Energy Storage Project Efforts Targeted for Development of Advanced Materials for High Energy and Ultra High Energy Cells and their Design and Development

NASA In-House Efforts

- Layered Metal Oxide Cathode Development – JPL
- High Voltage, Flame Retardant Electrolyte Development – JPL
- Si-based Composite Anode Development – GRC

NASA Research Announcement NNC08ZP022N Research and Development of Battery Cell Components

- NEI Corp., "Mixed Metal Composite Oxides for High Energy Li-ion Batteries"
- University of Texas at Austin, "Development of High Capacity Layered Oxide Cathodes"
- Physical Sciences, "Metal Phosphate Coating for Improved Cathode Material Safety"
- Yardney, "Flame-retardant, Electrochemically Stable Electrolyte for Lithium-ion Batteries"
- Lockheed Martin Space Systems Company, "Advanced Nanostructured Silicon Composite Anode Program"
- Georgia Tech Research Corp. & Clemson University, "Design of Resilient Silicon Anodes"
- Giner, "Control of Internal and External Short Circuits in Lithium-Ion Batteries"

Component Scale-up and Cell Design and Development for High Energy and Ultra High Energy Cells

- Saft America

NASA Exploration Systems and Leveraged Efforts Supporting Development of Advanced Materials and Cells

2008 Phase I SBIRS/STTRs

- Yardney Technical Products – Advanced Battery Materials for Rechargeable Advanced Space-Rated Li-Ion Batteries
- Superior Graphite Co. – SiLix-C Nanocomposites for High Energy Density Li-ion Battery Anodes
- Physical Sciences, Inc. – Silicon Whisker and Carbon Nanofiber Composite Anode
- TH Chem, Inc. – New Li Battery Chemistry for Improved Performance
- TDA Research, Inc. -- High Capacity Anodes for Advanced Lithium Ion Batteries
- EIC Laboratories, Inc. – Nanoshell Encapsulated Li-ion Battery Anodes for Long Cycle Life
- Giner, Inc. – Non-Flammable, High Voltage Electrolytes for Lithium Ion Batteries
- NEI Corp – High Capacity and High Voltage Composite Oxide Cathode for Li-ion Batteries (STTR)

Phase II SBIRs

Yardney Technical Products – Nano-Engineered Anode Materials for Rapid Recharge High Energy Density Lithium-ion Batteries

IPP Seed Fund Program

Quallion, LLC – Safer Lithium-Ion Rechargeable Cells for Energy Storage

The Boeing Company and Teledyne Energy Systems Human-Rated Space Power Systems Pallet Demonstrating Fuel Cells, Lithium-Ion Batteries and Advanced Thermal Management Technologies

NSF-EPSCoR

University of Puerto Rico – Infrastructure Building Towards an Institute for Functional Nanomaterials in Puerto Rico

University of Puerto Rico – Space Exploration Enabling Power Systems: Partnership to Develop the Fundamental Nanoscience at UPR and Perform the Corresponding Proof-of-Concept at NASA GRC

Interagency Power Working Group

Navy, AFRL, Army, DoE, NASA – leverage results from all agencies, e.g. high voltage cathode research

Focused Session Papers

This session features some of the NASA in-house and contracted efforts focused on development of advanced materials for Exploration Missions

- Advanced Materials and Cell Components for NASA's Exploration Missions; *Concha Reid*, NASA Glenn Research Center
- Advanced Nanostructured Cathode Materials for NASA's Applications; *Nader M. Hagh*, Mumu Moorthi, and Ganesh Skandan, NEI Corporation; Shirley Meng, University of California San Diego; William C. West and Ratnakumar Bugga, Jet Propulsion Lab; and Concha Reid, NASA Glenn Research Center
- High Energy Density Cathodes for Next Generation Lithium-Ion Batteries; *Arumugam Manthiram*, University of Texas at Austin
- Characterization Studies of Li2MnO3-LiMO2 (M=Mn, Co, Ni) Cathodes; *William West*, Marshall Smart, and Ratnakumar Bugga, Jet Propulsion Laboratory; Ganesh Skandan and Nader Hagh, NEI Corporation
- Improved Cathode Material Safety via a Metal Phosphate Coating; *C. M. Lang*, K. Constantine, and A. Newman, Physical Sciences, Inc.
- Development of Non-Flammable Electrolytes for Lithium-Ion Batteries; *Brett L. Lucht*, University of Rhode Island; and Boris Ravdel, Yardney Technical Products
- Development of Advanced Electrode Materials for Rechargeable Space Rated Li-Ion Batteries; *Joe Gnanaraj*, Yardney Technical Products

Focused Session Papers

- Nanostructured Composites for High Capacity Anodes; *Justin Golightly*, Vince Teofilo, Ashley Pietz, Jorge Bonilla, Lowell McCoy, Jane Bonvallet, and Mark Isaacson, Lockheed Martin Space Systems Company
- Nano-Silicon Anodes; Alexandre Magasinski, Benjamin Hertzberg, Patrick Dixon, Frank Grant Jones, and *Gleb Yushin*, School of Materials Science & Engineering, Georgia Institute of Technology; Bogdan Zdyrko and Igor Luzinov, Department of Material Science, Clemson University; Thomas F. Fuller, School of Chemical and Biomolecular Engineering, Georgia Institute of Technology
- Silicon Whisker and Carbon Nanofiber Composite Anode for Lithium-Ion Batteries; *Junqing Ma*, Aron Newman, John Lennhoff, Christopher Lang, Alex Elliott, and Kara Constantine, Physical Sciences, Inc.
- Carbon/Silicon Composite Anodes for Advanced Lithium-Ion Batteries; *John Olson*, Recla Dean, Trudy Scholten, and Steve Dietz, TDA Research